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ABSTRACT

This paper presents a discussion of various statistical concepts and techniques in light of two propositions. The first is that researchers need to select analytical techniques that prevent them from committing Type VI errors, which are inconsistencies between the research question and the statistical analysis. The second is that many statistical techniques are interrelated on a conceptual level. In addition, a list of resources is presented to assist researchers who want to pursue a more detailed study of the issues presented. The topics discussed are: (1) distinguishing between statistical analysis issues and research design issues; (2) examining various concerns with the use of structural equation modeling; (3) considering both statistical and practical significance of results; (4) reflecting on when and how to control for inflated Type I error rates; and (5) distinguishing between research questions that require multivariate analyses and those that require univariate analyses. This paper may provide researchers with more in-depth understanding of how a given technique may address a research question accurately. (Contains 1 table and 35 references.) (Author/SLD)

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The Importance of Matching the Analytical Technique with the Research Question: A Discussion of Current Research Issues

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Abstract

The purpose of this paper is to present a discussion of various statistical concepts and techniques in light of two propositions. First, researchers need to select analytical techniques that prevent them from committing Type VI errors, which is the inconsistency between the research question and the statistical analysis. Second, many statistical techniques are interrelated on a conceptual level. In addition, a list of resources is presented to assist researchers who want to pursue a more detailed study of the issues presented. The topics presented for discussion consist of (a) distinguishing between statistical analysis issues and research design issues, (b) examining various concerns with the use of structural equation modeling, (c) considering both statistical and practical significance of results, (d) reflecting on when and how to control for inflated Type I error rates, and (e) distinguishing between research questions that require multivariate analyses and those that require univariate analyses. This presentation may provide researchers with more in-depth understanding of how a given technique may accurately address one's research question.

The Importance of Matching the Analytical Technique with the Research Question: A Discussion of Current Research Issues

The discussion of the statistical and research issues presented in this paper is focused on the underlying proposition that the analytical technique used by the researcher should not lead to a Type VI error. That is, the statistical technique should not be inconsistent with the research question (Newman, I., Deitchman, R., Burkholder, J., Sanders, R., & Ervin, L. 1976). The topics presented for discussion consist of the following: (a) distinguishing between statistical analysis issues and research design issues, (b) examining of various concerns with the use of structural equation modeling, (c) considering both statistical and practical significance of results, (d) reflecting on when and how to control for inflated Type I error rates, and (e) distinguishing between research questions that require multivariate analyses and those that require univariate analyses.

The tremendous analytical power of today's computers makes it relatively easy for instructors to apply data management and analysis. Moreover, the point-and-click environment of software almost entices one to mechanically use statistics. While such ease of use lends efficiency to expert researchers' work it may only encourage thoughtlessness and lack of understanding among novices (both instructors and their students) who fail to grasp the complete meaning of analyses they undertake. We believe if one understands how issues of research design, statistics, and univariate and multivariate analyses, practical significance and statistical significance are interrelated, instructors can select and use statistical techniques mindfully rather than mindlessly. As a result, they are then empowered to teach the concepts more effectively, and thereby decrease the likelihood of making Type VI errors in their own research and the research of their students.

Issues Addressed by Statistical Analysis Versus Issues Addressed by Research Designs

Issues addressed by the design of a study are distinct from issues addressed by the statistical analyses. Although this distinction may seem obvious, it is vastly overlooked by too many researchers. In 1980 the United States Supreme Court based decisions in discrimination suits on statistical analyses that found significant relationships (i.e., correlation values) from studies that lacked sufficient research design controls of the types discussed by Fisher (1971); Newman and Newman, (1994); and Campbell and Stanley, (1963). Such legal decisions incorrectly characterized sophisticated statistical analyses as cause-effect relationships.

All tests of significance are tests of relationships. Therefore, each one of those tests can be mathematically translated into the degree of relationship between the variables. Conversely, if one knows the sample size, all mathematical relationships can be converted into tests of significance. As noted by McNeil, Newman, and Kelley (1996), a *t* test is equivalent to a point-biserial correlation; an *F* test is equivalent to an *eta* value or an *R* value; and a 2X2 chi square value is equivalent to a *phi* coefficient (see Table 1). The point biserial correlation, *phi*, *eta*, *t*, *R*, *F* and chi square values are all related. Any test of significance merely gives a probability estimate that a relationship is not due to random variation. It yields no information about the causal nature of that relationship (i.e., the degree of internal validity). Only to the extent that a research design has total internal validity can one assume causality.

Concerns Related to the Use of Structural Equation Modeling

Structural Equation Modeling (SEM) has many advantages in that it forces the researcher to develop or come from a theoretical frame, which frequently improves the quality of the research, tends to be more replicable, and more effectively adds to the body of knowledge. That is, hypotheses are logically deduced from theory. If a logical, expected theoretically-driven

relationship is found, these results are considered to be a stronger indicator of cause than if one found a relationship without theoretical or logical support. This strength has another side however, one that warrants caution in drawing conclusions too quickly. That is SEM may show very different models that imply different causal relationships with equally good estimates of goodness-of-fit index values. This is possible because SEM really tests how well the data fit the models, not necessarily theories, and models are not necessarily theoretically based.

With all its strengths and mathematical sophistication, studies that employ SEM may suffer from Type VI errors, that is, inconsistency between the research question and the statistical analysis. Type VI errors can be caused by a number of problems.

Lack of interaction terms in SEM. If the theory driving the study assumes interaction effects, an inconsistency between the analysis and the theory would exist if the researcher does not include interaction effects in the model. Evident in the published literature are too many studies by authors whose SEM analyses ignore the interaction effects in their theories. In addition, a researcher who is committed to using SEM may be less inclined to propose research questions that involve interaction effects.

Researchers who use SEM often deal with interaction effects by analyzing separate models for variables that interact. This simple and elegant solution might work in situations with when few variables that interact, if it is a first order interaction and the variables are dichotomous in nature rather than ordinal or interval. The interaction problem becomes considerably more complicated in situations with multiple interactions; the variables are ordinal or interval in nature; and higher order (i.e., second, third, etc.) interaction exists. These situations would result in Type VI errors when SEM is used. No mathematical model, of which we are aware, that can adequately assess such research questions (Newman & Marth, 1995).

Information not provided by goodness-of-fit indexes. These goodness of fit measures (e.g., CFI, NFI, NNFI, IFI, RFI, PNFI, PCFI, chi square value, GFI, RMSR, RMSEA, chi square divided by degrees of freedom, and AGFI.) All of these measures, except for chi square value, are not attached to tests of significance, and frequently give different results. All of these goodness-of-fit measures, however, are based on a similar concept. That is, each of these measures assesses the model's ability to reproduce the correlation matrix.

This method of assessing model fit can lead to an incorrect assessment under two possible scenarios. First, it is possible for a model that contains numerous paths to produce a goodness-of-fit value that indicates a good level of fit in spite of the fact that none of the path values are statistically significant. Second, it is possible for the model to effectively reproduce the correlation matrix even when some of the relationships are in the opposite direction from the direction predicted by the theory.

We believe it is logical to consider the number of path values that are statistically significant in the predicted direction. This method of assessing goodness of fit is not based on the model's ability to reproduce the correlation matrix, but rather on its ability to reflect the path values as suggested by theory. This approach has been referred to as the Binomial Index of Model Fit (Fraas & Newman, 1994; Newman, Fraas, & Norfolk, 1995).

SEM and confirmatory factor analysis. Most SEM is used to determine if the factors are good estimates of the theoretical factor structure. It is very possible that two factors fit the structure well and one does not. For such a case, the traditional goodness-of-fit techniques may simply indicate a poor fit without revealing which factors do not fit the structure. The Kaiser Factor Matching technique, however, would indicate which of the two factors fit well (Newman, Dimitrov, & Waechter, 2000). According to these authors, Kaiser Factor Matching should be

used along with the more traditional estimates to get a better picture of the relationships of the factors to the underlying theoretical constructs. Using more than one method of assessing the data is likely to give a more accurate picture and provide a better understanding of the data.

SEM and measurement error. SEM purports to control for measurement error, a safeguard too hastily assumed by researchers who do not appreciate complexities of the issue of error. An over simplification of this procedure is that instead of using the indicator variables, SEM uses the underlying factors as predictor variables. The assumption is that the factors are stable and, therefore, they are controlling for measurement error. While probably reducing measurement error, it does not eliminate it. The factors, however, may cause other types of errors because they may be quite sample specific. Thus, while almost never implemented, cross validation of the model to estimate its stability is warranted.

Incorporating practical significance levels. We believe it is important for researchers to formulate research questions that incorporate practical significance levels (e.g., effect sizes). Researchers who use SEM in connection with such research questions must develop goodness-of-fit measures that are capable of assessing and modified questions such as, "the difference between means are not 0 but are 5 units," or "the relationship is not 0, but is .3."

Importance of Statistical Significance and Practical Significance

The importance of effect size is a frequently discussed topic in today's research literature (Kirk, 1996; Levin, 1996; Levin & Robinson, 2000; Robinson & Levin, 1997; Thompson, 1989b, 1996, 1997, 1998, 1999a, 1999b, 1999c). Two important issues are currently being discussed. One issue relates to the question: How large should an effect size be in order for it to be practically significant? A second issue relates to the question: Should a researcher be concerned with practical significance, statistical significance, or both?

Establishing the practical significance level. When dealing with the issue of how large should an effect size be in order for it to be considered practically significant, Newman and Newman (2000) presented the case that even small effect sizes, as measured by small R-squared values, may be important, that is, practically significant. They concluded that small R-squared values may be very valuable and useful depending on the research question being asked and the size of the population. This position, which is supported by Rosenthal and Rosnow (1991) and Deming (1982), suggests that practical significance should be measured in a relative sense rather than an absolute manner.

Incorporating the practical significance level into the hypotheses. Fraas and Newman (2000, 2001) and Robinson and Levin (1997) argued that consideration of either effect sizes or tests of significance alone are insufficient. One needs to consider both. Fraas and Newman (2000) discussed the testing of non-nil null hypotheses (i.e., hypotheses that incorporate non-zero values). The formulation of such hypotheses allows one to accurately reflect a research question that incorporates a practical significant value, thus avoiding a Type VI error.

To illustrate the use of a non-nil null hypothesis, consider a study designed to test the effectiveness of two treatments intended to produce weight losses for cardiac patients. Researchers initially need to establish how large the difference the weight-loss means of the two groups must be in order for it to be considered important, that is, practically significant. Fraas and Newman (2000) expressed the view that this process is probably best undertaken by involving practitioners and researchers in the field.

For the purpose of this illustration, practitioners and researchers decided any difference between the group means greater than 10 pounds would be considered practically significant. For this practical significance level, the non-nil null hypothesis that Mean 1 minus Mean 2 equals 10 is

more clinically meaningful than the nil null hypothesis that Mean 1 minus Mean 2 equals zero. That is, instead of saying we are 95% confident the difference is greater than zero, we can say we are 95% confident the difference is greater than 10. If experts determined that a difference of 10 pounds was minimally required for clinical benefit, the latter statement is far more meaningful and useful.

The use of non-nil null hypotheses requires researchers and practitioners to identify what is clinically or pragmatically meaningful before initiating the research. The decisions determining the appropriate effect size need to be related to the purpose for doing the research. Newman, Ridenour, Newman, and DeMarco (in press) emphasize the importance that researchers frame their research question so it is consistent with their purpose. This clear understanding of purpose (i.e., who the outcome is intended to inform) is necessary for the researcher to identify the appropriate effect size. Without looking at the research question in the context of its purpose, one cannot identify an appropriate and useful clinical effect size. The incorporation of the effect size into the research question dictates that statistical significance is not considered independent of the practical significance level.

Testing non-nil null hypotheses. Once the appropriate clinical effect size is identified, Fraas and Newman (2000) suggest one technique that could be used to test a non-nil null hypothesis is a randomization test. The use of a randomization test, which generates its own distributions, is used to determine if the observed difference adjusted for the practical significance level is unlikely to be due to chance variation. It should be noted, however, that Newman and Fraas (2001) also conducted a Monte Carlo study regarding the impact of including the practical significance level into the research question on the Type I error rates of independent *t* tests of two

group means. The results revealed negligible impacts of such tests on the Type I error rates. Thus, non-nil null hypotheses may, under certain conditions, be tested with parametric tests.

Statistical significance versus replication. A concept often overlooked when dealing with effect sizes and tests of significance is the replication of the findings. Because a study is statistically significant does not mean it is replicable (i.e., tests of significance do not provide information regarding replication). Whenever possible, the ability to replicate one's findings should be provided through the use of cross validation techniques applied (a) to the original sample and/or a new sample, (b) by different researchers, and (c) under different conditions. A significant chasm exists in the literature regarding the topic of replication. Compared to the growing number of articles and presentations on the importance of tests of significance versus effect size, one finds scant attention to the importance of replication. We make a strong call for more emphasis to be on the reporting of replication estimates.

Controlling Type I Error Rates

Numerous authors discuss the need to control for inflated Type I error rates in studies that involve multiple statistical tests. Some express a major concern in the mechanical manner in which the various methods of controlling for Type I errors is applied and taught (Kirk, 1982; Newman, Croom, Mugrage, & Hoedt, 1983; Newman & Fry, 1972; Newman, Fraas, & Laux, 2000; Stevens, 1996; Toothaker, 1991). Newman, Fraas, et al. suggest a non-mechanical approach that requires the researcher reflect on three elements of the adjustment process. First, the researcher needs to identify the error rate unit or units (i.e., the various groupings of tests for which adjustments are to be made). Second, adjustments are not made for tests that are directional and based on theory or previous results. Newman, Fraas, et al. suggest that if a researcher adjust the alpha levels for tests predicted from previous experience or theory, the researcher will probably

overcorrect for possible inflated Type I errors. Such an outcome would increase the likelihood of Type II errors being committed. Third, the alpha levels for the non-directional tests in a given error rate unit are adjusted for the number of such tests.

When asking relatively sophisticated students if they controlled for inflated Type I error rates due to multiple tests of significance, advanced research students we have worked with generally indicate they have. If we further ask them which method they used, why they chose that method, and what the error unit is, we seldom get an answer that indicates a thoughtful approach. The procedures they used tended to be selected and applied mechanically. They have difficulty in justifying the procedure used. The approach outlined by Newman, Fraas, et al. (2000) may encourage students to reflect on the rationale of the adjustment process rather than mechanically implementing a given technique.

Multivariate Tests Versus Univariate Tests

According to the authors of many statistics texts, when one has multiple dependent variables, multivariate analysis should be employed. The common reason for using multivariate analyses in such cases is that these analyses control for inflated Type I error rates. Unfortunately, this recommendation is frequently misunderstood since the overall multivariate test of significance is only one aspect of the multivariate testing procedure. When a significant multivariate test is followed by univariate tests to determine where the significant differences lie, a control for multiple tests is necessary to keep the Type I error rate from being inflated (Croom, 1986; Newman, Croom, Mugrage, & Hoedt, 1983). The most important consideration in determining whether one should use multivariate or univariate measures should be how well either univariate or multivariate analyses reflect the question of interest (Newman & Benz, 1987). If the question of interest is not related to the underlying construct of a set of independent variables, but is

instead related to each dependent variable, univariate analyses should be used. Multivariate analyses should only be used when one is interested in the underlying hypothetical construct of the composite set of dependent variables, which is very rarely the case (Jeremy Finn, October, 2001, personal communication).

An additional point should be made regarding the use of multivariate analyses. It appears to be a well accepted fact that all multivariate analysis of variance techniques are subsets of canonical analyses, just as traditional analysis of variance techniques are subsets of multiple regression analyses. (Note that canonical analysis is sometimes called multivariate regression.) In a canonical correlation the statistical analysis determines how well the underlying construct of a set of predictor variables predicts the underlying constructs of a set of criterion variables. It does not, however, answer the question: How well do these individual predictor variables predict these individual dependent variables simultaneously? If one is interested in that question and conducts a multivariate analysis, then a Type VI error is being made (i.e., the inconsistency in the research question and the statistical analyses).

Summary

Researchers must realize that today's computer statistical software allows them to easily provide extremely complicated statistical analyses of large and complicated databases. They must be cognizant, however, of a potential danger that such software generates. That is, researchers may allow the sophisticated analytical techniques contained in the computer software, such as multivariate techniques, to dictate how their analyses will be conducted. Such mechanical thinking may lead to an inconsistency between the research question and statistical analysis, that is, a Type VI error is committed. Not only are we advocates for thoughtful conceptualizing of

one's research question, we also strongly believe the type of data analysis used is inexorably dictated by that question.

The quality of research will be enhanced if practicing and future educational researchers along with the consumers of that research: (a) understand a study's degree of internal validity is addressed by its research design and not by its statistical analyses; (b) reflect on the advantages and disadvantages afforded researchers who use structural equation modeling as their analytic technique; (c) realize the need to consider both statistical and practical significance; (d) understand the rationale used for adjusting or not adjusting the alpha levels of multiple statistical tests, and (e) comprehend the differences between research questions that require the application of multivariate tests and those that should be analyzed with univariate tests. The issues addressed in this paper may cause researchers, graduate students, and consumers of research to reflective on the need to match one's analytical methods with the research question. Such reflection may be one step on the path that leads to higher quality research in education.

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Table 1

All Tests of Significance are Tests of Relationships

Test	Measure of Relationship
t test	r_{pb}; that is $t^2 = \frac{r_{pb}^2\ df}{1 - r^2_{pb}}$
Z test	r_{pb} (point biserial)
F test	η^2 (eta); could also be measured by R^2
X^2 test	ϕ which is $\frac{X^2}{N} = \phi^2$ (phi coefficient)
	when df = 1 or greater than 1 (contingency coefficient)
	$C^2 = \frac{X^2}{X^2 + N}$

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